Registration model for near-equatorial earth observation satellite images using automatic extraction of control points

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Abstract. Developing more accurate and efficient registration models for satellite images is important for remote sensing and GIS applications. Near-equatorial satellite image bands differ in viewing points, altitude, illumination, and satellite zenith, azimuth, and attitude. This study presents a comparison of band-to-band registration of near-equatorial satellite image bands. RazakSAT satellite image covering Kuala Lumpur - Pekan, Malaysia is investigated. The proposed method is performed by generating tie points to automatically generate control points (CPs) from the image using Envi software. The generated CPs are then applied to first-, second-, and third-order polynomials to calculate transformation coefficients and simulate different viewpoints. Verification is conducted by comparing the root mean square errors (RMSE) of these orders. The RMSE of the third polynomial transformation for misregistration is more accurate than that of the first- and second-order polynomial transformations. The RMSEs of the first-, second-, and third-order transformations range from 22.75 to 68.70, 17.9 to 52.15, and 12.00 to 29.25, respectively.

1. Introduction

Band-to-band registration is considered as one of the satellite image elements that can improve geometric correction. Most geometric errors in remotely sensed images are the result of band shifting, and are not only common in satellite images but are also found in spaceborne, unmanned aerial vehicles (UAV) and airborne platforms [1].

Correcting and overcoming bands shifting improve the reduction of geometric distortion in remotely sensed images, which, in turn, are applied in different applications, such as change detection and land cover classification, image fusion, and geometric correction [2, 3]. However, several algorithms for band-to-band registration, including manual, automatic, and a combination of the two techniques, have not been studied extensively [1].

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Numerous researchers have applied the automatic registration approach to correct bands shifting [4-9]. Many iterative methods for bands registration of remotely sensed images have been used to maximize or minimize similarities or differences, respectively, between base and sensed imageries without using control points (CPs). Bazen and Gerez, and Thevanaz and Unser employed pyramid method in their respective studies to decrease calculation time [10-11]. They studied the major steps of band registration, namely, (1) identification of control points, (2) image transformation model, and (3) image resampling. The conventional registration of remote sensing images is performed by selecting CPs from the entire image manually, then calculating transformation coefficients from the CPs. However, applying this approach is infeasible when large data are involved because the process is time-consuming [12-13]. By contrast, manual selection CPs are unnecessary if automatic registration techniques are applied. Automatic registration approaches are based on (1) local features or (2) intensity [14-15]. The second approach is applied by comparing brightness values (intensity) of base and slave images using image correlation metrics [15-18]. Several studies employed wavelet coefficient maxima to perform automatic registration [5], and others applied similarity of mutual information to register multi-sensor images [19]. Previous studies have also applied windows matching to find corresponding key points between a reference and sensed images [9]. Hierarchical technique has been used by researchers in image matching [20]. The intensity-based approach has unavoidable limitations; transformation elements between the base and slave images, such as skewing, scaling, shifting, and rotation, have small differences. Thus, the intensity-based approach is not suitable for separate viewpoints of remote sensing images. This approach is also highly sensitive to occlusion, which is apparent in images that were captured with differences in sensor altitude, illumination, and distant viewpoints [21]. Feature-based algorithm, however, attempts to find corresponding key points (or local features), such as lines, points, and contours, between images. It can be applied to remote sensing images through the following steps: (1) feature detection, (2) local feature matching, (3) mapping function design, and (4) image transformation and resampling [22]. This study provides a statistical assessment of these transformation methods by employing Envi software, which has been used less frequently in recent studies, and Arc Map software for the subsequent processing.

The objective of this study is to determine the most suitable polynomial transformation order to correct band-to-band registration of near-equatorial satellite (NEqO) images through automated extraction of ground control points (GCPs). Recommendations for image registration and geometric correction of NEqO satellite images using high spatial and temporal resolution are also presented in this paper.

2. Band-to-band registration processing

The proposed registration comparison method for band-to-band registration of NEqO satellite images is presented in Figure 1. First, tie CPs from the base and slave images are manually selected; then, these CPs are used by the method to automatically generate GCPs based on the correlation between the two images. Third, parameters of transformation are calculated from GCPs to perform band-to-band registration of NEqO satellite images. The transformation is performed by applying first-, second-, and third-order polynomial transformations. Verification is performed by comparing results of the polynomial transformations.
2.1. Study area and data set references
The study area is located in KL–Pekan, Malaysia and lies between 102°19′55″−103°27′08″E and 02°39′22″−02°50′36″N with an area of 2000 km², as shown in Figure 2. A RazakSAT satellite NEqO image, captured over Malaysia on August 1, 2009, is used in this study, as well as four multispectral bands (red, green, blue, and near infrared) and one panchromatic band with spatial resolution of 5 m and 2.5 m, respectively.
2.2. Master band selecting
Selecting the master band was one of the difficulties encountered in this study because all of the remotely sensed image bands in the covered area exhibited slight differences in stretching, skewing, rotation, and noise [1, 4, 7 - 9]. The green band has fewer defects and is more suitable as the master band for band registration; it also has less noise than other bands, which are identical.

2.3. Automatic extraction of GCPs
Coefficients of the transformation function are determined when GCPs are identified. In this study, automatic extraction of GCPs was applied after tie CPs were manually selected to determine the most accurate key points based on the correlation between the base and slave images; then, these CPs were applied to polynomial transformations to obtain the accurate registration for NEqO satellite images [1, 23-25]. After spatial transformation of the image, registered imagery pixel intensities with integer coordinates were identified by interpolation of the nearest neighbor [1, 13].
2.4. Polynomial transform function
A polynomial transform function is a transformation for linear distortion, which is expressed by the following formula:

\[ u = a_0 + a_1 x + a_2 y \] (1)
\[ v = b_0 + b_1 x + b_2 y \] (2)

Where \(a_0\) and \(b_0\) are shifting coefficients; \(a_1\), \(a_2\), \(b_1\), and \(b_2\) are the scaling, shearing, skewing, and rotational coefficients; and \((u, v)\) and \((x, y)\) are CP coordinates in the slave and base images, respectively. Three independent CPs are needed to calculate the equation coefficients. Increasing the number of CPs by using the least squares method leads to higher accuracy of registration. Increasing the number of transformation function parameters results in better matching between images [17, 26].

3. Experimental results
To perform band registration on the NEqO satellite image, the researchers considered the green band as the base image, and the red, blue, and near infrared bands as slave images. Five tie points were selected manually between the base and slave images to automatically generate 50 CPs using image correlations in the Envi environment. The CPs were then applied to first-, second-, and third-order polynomial transformations to determine the coefficient transformation function. Then, non-overlapping areas were removed by performing masking and clipping. Tables 1, 2, and 3 demonstrate the results of CP processing and describe the root mean square errors (RMSE) of band registration.

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<thead>
<tr>
<th>Polynomial orders</th>
<th>Tie points</th>
<th>Generated GCPs</th>
<th>RMSE (pixel)</th>
<th>RMSE (meter)</th>
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<tbody>
<tr>
<td>First</td>
<td>5</td>
<td>50</td>
<td>13.74</td>
<td>68.70</td>
</tr>
<tr>
<td>Second</td>
<td>5</td>
<td>50</td>
<td>10.43</td>
<td>52.15</td>
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<tr>
<td>Third</td>
<td>5</td>
<td>50</td>
<td>05.11</td>
<td>25.60</td>
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<tr>
<td>First</td>
<td>5</td>
<td>50</td>
<td>12.73</td>
<td>63.65</td>
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<td>Second</td>
<td>5</td>
<td>50</td>
<td>09.80</td>
<td>49.00</td>
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<tr>
<td>Third</td>
<td>5</td>
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<td>05.58</td>
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<td>Third</td>
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Tables 1, 2, and 3 show that the third-order polynomial transformation produced the most accurate RMSE, and the second-order polynomial has a more accurate result than the first-order one. The RMSEs of band registration between green bands and blue, red, and infrared bands were 25.60, 29.25, and 12.00 m, respectively. Thus, the polynomial transformation cannot address nonlinear transformations [17, 26]. The CPs used in this type of transformation are also inaccurate because the image has a high level of non-linear distortion [26]. Moreover, the appearance of CPs are difficult to recognize [13, 17, 18, 26, 27]. Band-to-band registration is a serious problem in remote sensing data, but when analysts obtain a solution to this problem, they can perform digital image processing. Figure 3 presents the final band registration of the NEqO satellite image.

![Final band-to-band registered image](image)  
Figure 3. Final band-to-band registered image.

4. Conclusion
Near equatorial satellite image band shifting registration is a problem for different remotely sensed images. NEqO satellite image bands are affected by spectral shifting from differences in altitude, capturing time, satellite zenith and azimuth, solar zenith and azimuth, viewing points, and satellite behavior during image capture. The proposed comparison method for band registration of the NEqO satellite image is performed by selecting tie points manually from the base and slave images to generate GCPs of NEqO satellite image bands using first-, second-, and third-order polynomial transformations. The original RazakSAT image bands are registered. The third-order polynomial transformation has the most accurate RMSE, and the RMSEs of first-, second-, and third-order range from 22.75 to 68.70, 17.9 to 52.15, and 12.00 to 29.25, respectively. Automatic band co-registration of NEqO satellite images require further research.
Reference


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[20] Zhang C and Fraser C 2005 Automated registration of high-resolution satellite imagery for change detection  *ISPRS*. 36 (1) 3–8
